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**Beacon Monitoring Would Reduce
Communications Requirements
and Ground Interactions with
Spacecraft**

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BEACON MONITORING WOULD REDUCE COMMUNICATIONS REQUIREMENTS AND GROUND INTERACTIONS WITH SPACECRAFT

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Abstract

Beacon Monitoring denotes a concept for providing a spacecraft with a simple way to notify the ground when it requires interaction. Historically, spacecraft have had to transmit large amounts of system status data to operators on the ground requiring reliable communications links, lengthy transmission times, and complex data reception and detection equipment. Operations experts must monitor and analyze this data and decide when further interaction with the spacecraft is required. In the future, many spacecraft will have the intelligence to analyze their status data on their own. The responsibility for deciding when interaction is required between the ground and the spacecraft will transfer to the spacecraft. The beacon monitor concept reduces the need for the spacecraft to transmit routine telemetry data and for routine operator interaction. Instead it provides the ability for the spacecraft to transmit a simple message to the ground (in the form of one of four subcarrier tone frequencies) which corresponds to one of four ground action requests. The simplicity of the beacon tones allows detection at lower signal-to-noise ratios, with smaller receiving antennas, shorter tracking times, and significantly less complex and expensive receiving and detection equipment than that required for traditional telemetry. Beacon detection efficiency also permits lower spacecraft transmitter power, less

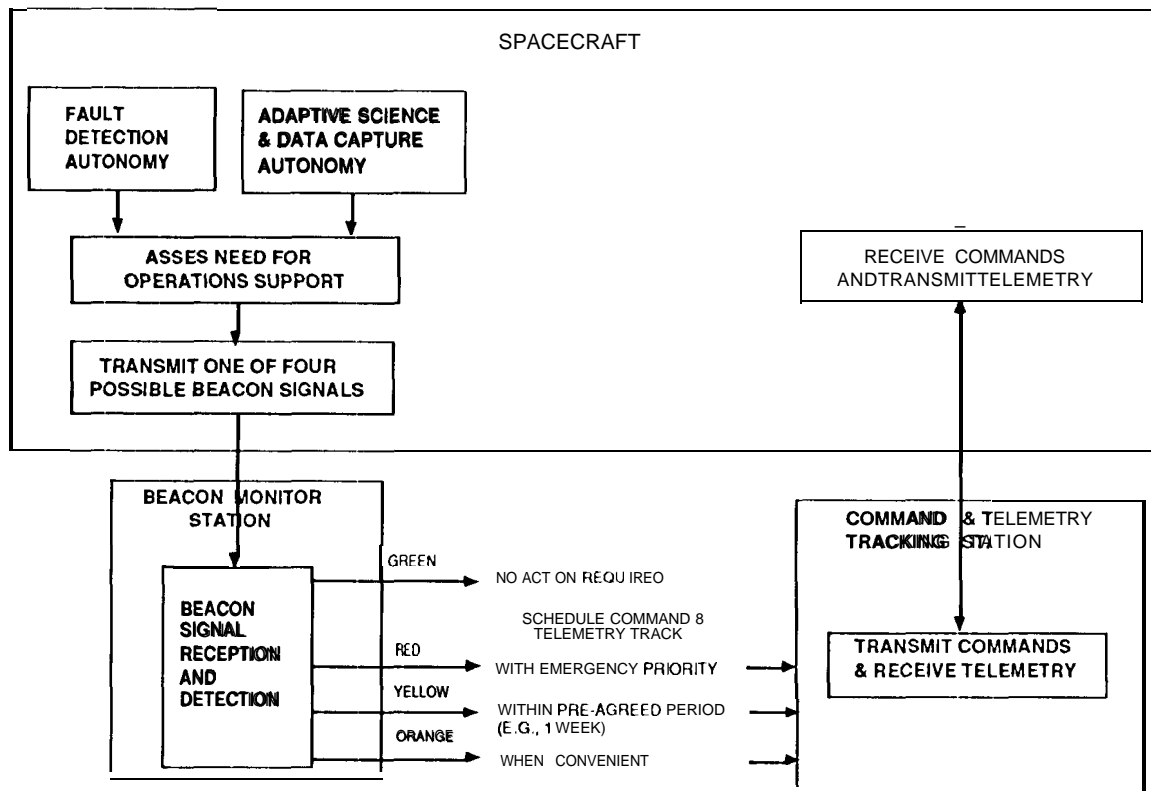
accurate spacecraft antenna pointing, reduced thruster firings, and reduced use of attitude control propellant.

introduction

A change in the way we do routine spacecraft monitoring from traditional telemetry data to beacon monitor signals can provide the following advantages:

- use of smaller ground antenna apertures
- use of simpler, lower cost receiving and detection equipment
- significantly shorter tracks
- more flexible scheduling
- lower s/c transmitter power
- relaxed s/c antenna pointing requirements
- reduced s/c thruster firings and attitude control propellant usage
- less routine involvement of human experts
- easier automation of ground response actions
- less monitor data capture, display, analysis, and archive
- lower tracking costs
- lower operations costs
- improved mission reliability
- the ability of the Deep Space Network antennas to support the command and data return requirements of many more s/c with existing resources.

FIGURE 1: BEACON MONITOR BLOCK DIAGRAM



By the use of simple subcarrier signals, the s/c can send one of the following four “messages” to the ground:

- 1- Green: no action required. I am functioning normally and no interaction with operations experts is required
- 2- Red: contact me as soon as possible. I require operations support on an emergency basis.
- 3- Yellow: contact me within a certain pre-agreed amount of time or I will start performing in a degraded mode (running-out of memory, overwriting data, running out of commands, etc.)
- 4- Orange: Contact me at your convenience. An on-board event has occurred that maybe of interest to

operations and that the ground may want to collect information about sooner than the next scheduled telemetry contact.

The current operational concept for beacon monitoring is that the s/c will point at earth and continuously transmit one of the four beacon signals. Once a day, when it is convenient, the ground will monitor the beacon. If it is green, it will be logged in and the spacecraft will be ignored until the next day. If the beacon is found to be red, yellow, or orange, the ground will schedule a traditional telemetry track and command the spacecraft to begin downlinking telemetry. The procedures for scheduling these tracks will vary as a function of the difference in urgency between the red, yellow, and orange beacons. A current DSN study is looking at automating the beacon response on the ground to

autonomously notify operators and schedule telemetry passes [1].

Beacon monitoring is most effective for missions that have phases with long periods between scheduled communication tracks. One example would be an interplanetary spacecraft in low activity cruise mode. Another example might be an orbiting satellite with event driven science data capture autonomy and adequate on-board data storage capacity (looking for volcanic eruptions, say). The beacon would be used to notify the ground that the satellite had observed a volcano, captured data, and was ready to return this data to the ground.

For spacecraft that require hours of downlink per day to return prime mission science data, another beacon concept is to remove routine engineering monitor data from the link, dedicate the telemetry link to 100% science data, and use a beacon link to notify the ground when an engineering event has occurred requiring ground action,

Evolving Spacecraft Autonomy

Current spacecraft are being designed to spend significantly longer periods between ground contacts. More capable on-board computers, larger on-board solid state memories, and more, “smarter”, on-board software characterize spacecraft design trends that enable more autonomy.

Flight software that provides on-board, self-monitoring capabilities such as SELMON [2] and BEAM [3] will allow s/c to autonomously identify engineering anomalies. Future s/c will be able to respond to a large class of these anomalies without requiring ground interaction. For a remaining set of anomalies, the s/c will perform adaptive engineering data capture, store the anomaly data on-board, and use the beacon to notify the ground that it has detected an event requiring ground action and is ready to downlink analysis data to

the ground as soon as a telemetry link can be scheduled.

On-board fault recovery autonomy software provides spacecraft with the ability to safe themselves without ground interaction for many days following an anomaly. The JPL Pluto, Europa, and Solar Probe missions self-safing specification is 2 weeks. A weekly telemetry link would allow up to half of this 2 week ground response clock to “run out” before a problem was reported. Daily beacon passes will allow prompt discovery and ground response. For particularly reliable spacecraft or for spacecraft where less prompt anomaly discovery by the ground makes sense, beacon tracking can be done every other day, or maybe skipped over weekends.

Besides being equipped with the self-monitor & self-safing engineering autonomy described above, new spacecraft will exploit event-driven adaptive, science capture autonomy as well. New missions with less predictable orbits, target models, and less need for pre-coordinated ground events, will use on-board science autonomy to take data as it becomes available. The beacon link allows notification of the ground when adaptive science data capture and adaptive on-board data compression has resulted in the spacecraft memory being ready for downlink. Just as a two week spacecraft capability for unattended survival relaxes engineering anomaly response time requirements, spacecraft memory margin can be used to relax ground response time requirements to beacon requests for science data downlinks.

The beacon concept supports current trends in s/c autonomy including self-monitor, on-board fault protection, adaptive data capture, and long periods between scheduled routine telemetry tracks.

Beacon Signal Efficiency

The simplicity of the beacon signal provides communication efficiency that

can simplify both flight and ground system operations. The performance of a link designed to support traditional 100 bps telemetry can be improved by a factor of 1000 for beacon tone detection that may be performed by integrating the beacon subcarrier for 10 seconds. Even more dramatic gains from integration times of up to 1000 seconds are possible for spacecraft with oscillators with good short-term drift and phase noise behavior [4]. Improved performance due to the beacon link can be traded to reduce both flight and ground system performance requirements.

Ground System Simplicity Gains

One obvious way to exploit the performance advantage of a beacon link is to use a smaller receiving antenna on the ground. For the Pluto Express spacecraft telemetry system (2 meter s/c high gain antenna, 5 watt X band transmitter), the beacon signal could be received by a 3 meter ground antenna out to the range of Jupiter, and by an 8 meter ground antenna out to the range of Pluto [4].

Beacon tones can be detected without the need for symbol synchronizers, convolutional decoders, Reed-Solomon decoders, frame synchronizers, depacketizers, and all the complex ground equipment required for telemetry recovery. Likewise, many ground telemetry data handling tasks such as GCF transmission, data logging, staging, distribution, decommutation, display, and archiving are not required for beacon monitoring. The results of a beacon track can be simply logged onto a page on the internet.

With a small antenna and simple tone detection equipment the option of using university sites to perform beacon monitoring becomes a possibility. A joint activity between JPL and the US Air Force Academy is currently being studied to launch a FALCONSAT containing a beacon signal source and conduct an open student competition to see who can successfully detect a few weeks worth of

beacon tone changes using the lowest cost ground system design.

Flight System Simplicity Gains

Some possible ways to exploit the performance advantage of a beacon link on the spacecraft include lowering the transmitter power in beacon mode and/or reducing spacecraft antenna pointing requirements. For long duration missions, being able to fly extended periods in a wider limit cycle can significantly reduce the number of thruster firings, help meet thruster lifetime goals, and save attitude control propellant. At the cost of some added ground scheduling constraints, beacon downlinks can be scheduled to occur only once or twice a day at a pre-agreed time, further saving spacecraft resources.

Missions that have overconstrained spacecraft pointing such as solar electric propulsion often can't meet high gain antenna pointing requirements while simultaneously pointing the solar panels and aligning the engine thrust vector. A wide beam width medium gain antenna may be able to maintain a beacon link when a telemetry link isn't possible.

It is worth noting that here is no additional cost on-board the spacecraft to generate the beacon tone signals - existing capabilities of the NASA Standard Small Deep Transponder (SDST) permit transmission of the beacon subcarrier tones with no modifications.

Reduced Tracking Time

As NASA moves to full cost accounting, missions will be charged for the DSN tracking time that they schedule. Current charge for a 34 meter Deep Space Station (in '97 dollars) is \$1,190 per hour. For a long duration mission like Pluto Express, replacing a daily four hour telemetry track (plus an additional hour of required pre and post-cal time) with daily beacon tracks and going to monthly telemetry collection, will save over \$20 million dollars per spacecraft.

A single 34 meter station can support at most 6 missions, each requiring a daily 4 hour telemetry track for monitoring (actually less because of viewperiods, station maintenance, and pre & post calcs). A single beacon monitor station could support the monitoring of dozens of spacecraft, freeing up time on the 34 meter antennas to perform infrequent telemetry downlink for routine ground archive and to perform occasional adaptive beacon requested tracks to downlink special, adaptively collected science or engineering anomaly analysis data,

Beacon Tone Radiometric Data

The beacon detection system being prototype by the DSN will have the capability of acquiring and processing 1-way doppler from the beacon signal and using this information to perform trajectory prediction. This capability is important, as it would allow beacon tracks to replace many traditional large antenna tracks routinely scheduled to collect radiometric data. The goal is to provide the beacon system with it's own, self-contained ability to do trajectory determination, antenna pointing, and frequency tuning prediction [1].

Telemetry Station Scheduling

DSN large antenna scheduling procedures require tracking requests to be submitted and negotiated months ahead of time. There are short-term scheduling procedures (though disruptive) for declaring a spacecraft emergency and commandeering tracks away from other scheduled users (a red beacon response). Currently there are no procedures for quick turn-around, adaptive scheduling of tracks (yellow or orange beacon responses). One vision is that this demand access scheduling capability will become available as more and more missions use beacon links to reduce telemetry station loading, and thus more schedulable resource becomes available. A short term work-around in the current

situation is for projects to pre-negotiate periodic tracks and then simply release them a day or two ahead of time when a green beacon is detected.

Beacon Station Scheduling

A beacon track can be scheduled any time it is convenient for the ground, (constrained only by the beacon station viewperiod). The idea is to avoid the additional antenna scheduling paradigm where on-board spacecraft commands are coupled to the scheduling of ground resources. When ground schedules change, on-board commands must be changed and visa -versa. The beacon link obviates this coupling.

An interesting challenge is trying to perform beacon monitoring for spacecraft that may be performing unpredicted science capture. It is possible that at the time the ground is looking for a beacon, the spacecraft has turned its antenna off of earth-point to perform an adaptive science observation. This would result in notification to the project that no beacon was found when it was looked for. An operational work around that has been suggested for this possibility is to just respond to a "no beacon" signal by waiting any period from a couple of hours to a full day and trying again. Missions that expect to have a high amount of adaptive behavior may choose to wait through several "no beacon" tracks before they suspect a problem and request a telemetry pass. Missions that expect their spacecraft antenna to be pointed at earth at all times could request a telemetry pass following a single "no beacon" event.

Telmetry Instead of a Red Beacon ?

The current beacon concept requires detection of a red beacon to be followed by transmission from the ground of a command to the spacecraft to begin downlinking emergency telemetry. An alternative strategy has been proposed that suggests not using a red beacon at all, but simply allowing the s/c to request

emergency ground response by switching directly from downlinking its green beacon to downlinking telemetry. This approach saves the need for uplinking a command to switch to telemetry mode, and saves a 2 way light time delay in the availability of telemetry on the ground,

The disadvantage of this approach is that it eliminates an unambiguous signal requesting ground emergency response (the red beacon) and replaces it with an ambiguous signal (telmetry) that maybe there because of routine downlink scheduling or may be there due to a spacecraft anomaly. Two way light time delay in telemetry data recovery is not considered a major problem for spacecraft that can safe themselves for days or weeks. So the current beacon system is keeping with the use of the red tone to notify the ground that emergency response action is requested.

Conclusions

A scheme for using simple beacon subcarrier tone signals to allow spacecraft to request 1 of 4 ground actions has been described. Using a beacon monitoring strategy in place of the traditional routine downlink of telemetry data and subsequent analysis by operations analysts offers significant savings in ground station complexity, spacecraft resources, tracking time, and scheduling flexibility. A beacon monitoring link directly supports current trends in spacecraft design including self-monitor autonomy, the ability of spacecraft to safe themselves for significant periods of time without ground interaction, on-board adaptive science observations, on-board adaptive data capture, and adaptive data compression. Efficiencies offered by beacon monitoring may enable smarter support of an increasing number of smaller, better, faster missions in the future within limited DSN tracking station constraints.

REFERENCES

- (1) Donald Sweetnam & Henry Hotz, "Spacecraft Demand Access: Autonomy for Low-Cost Planetary Operations" Proceedings from 2nd International Symposium on Reducing the Costs of Spacecraft Ground Systems and Operations" Oxford, UK July 1997
- (2) Richard Doyle, "Determining the Loci of Anomalies Using Minimal Causal Models", IJCAI, Montreal, August 1995
- (3) Sandeep Gulati, "Wavelet-Theoretic Algorithms for On-Board Spacecraft Exception Analysis" AIAA Conference Reno, Nev, Jan 1999
- (4) Miles Sue, et al, "Automated Spacecraft Monitoring System Study Report" March 15, 1997 JPL Document # D-14396

OTHER 13 EACON PAPERS

- (5) Carraway, Crow, Doyle, & Wyatt "Beacon Monitoring Would Reduce Communications Requirements and Human Interactions with Remote Systems" NASA Tech Brief NPO- 19706, May 1997.
- (6) Sherwood, et. al "Flight Software implementation of the Beacon Monitor Experiment On the NASA New Millennium Deep Space 1(DS-1) Mission" Proceedings of the 2nd International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operations", Oxford, UK July 1997

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“Beacon monitoring” denotes a concept for allowing a spacecraft to notify local operators when it requires interaction.

Historically, spacecraft with little or no intelligence have had to transmit large amounts of system status data to operators, requiring reliable communications links, lengthy transmission times, and complex data reception and detection equipment. Operations experts must monitor and analyze this data and decide when further interaction with the spacecraft is required.

In the future, many spacecraft will have the intelligence to analyze their status data on their own. The responsibility for deciding when interaction is required between the ground and the spacecraft will transfer to the spacecraft. The beacon monitor concept reduces the need for the spacecraft to transmit routine telemetry data and for routine operator interaction. Instead, it provides the ability for the spacecraft to transmit a simple message that requests one of four actions from operations:

Green: Leave me alone. I am functioning normally and no interaction by operations experts is required.

Red: Contact me as soon as possible. I require operations support on an emergency priority basis.

Yellow: Contact me within a certain pre-agreed amount of time or I will start performing in a degraded mode (e.g., losing or over-writing data, running out of commands, etc..)

Orange: Contact me at your convenience. An event has occurred that may be of interest to operations and operations may want to collect information about sooner than the next scheduled telemetry contact.

The first intended applications for this technology are for JPL spacecraft that are equipped with appropriate on-board monitor and decision making intelligence (specifically, New Millennium and Pluto Express). These spacecraft will have the capability of requesting ground action by transmitting one of four beacon signals implemented as one of four possible subcarrier tone pairs or some other radio signaling scheme which is simple to generate and detect. The simplicity of the beacon signals allows detection at lower signal-to-noise ratios, with smaller receiving antennas, and with significantly less complex and expensive receiving and detection equipment than that required for traditional telemetry.

The JPL operational concept for using the beacon is that the spacecraft will point at earth and continuously transmit one of the four beacon tones. Once a day, whenever it is convenient, the ground will monitor the beacon. If it is green, it will be logged in and the spacecraft will be ignored until the next day. If the beacon is found to be red, yellow, or orange, the ground will schedule a traditional telemetry track and command the spacecraft when to begin downlinking telemetry. The procedures for scheduling these tracks will vary as a function of the difference in urgency between the red, yellow and orange beacons.